stantial improvement over the hard sphere theory of liquids. The use of equilibrium values of $g(\sigma)$ and $g(\lambda\sigma)$ in the evaluation of transport properties can be thought of as an important step in achieving a unified theory of the liquid stat

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Magnetic susceptibility of the free charge carriers in antimony telluride

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The magnetic properties of antimony telluride, (Sb_2Te_3), a typical partially conducting chalcogenide have so far been very sparingly studied. Matyas has studied the magnetic susceptibility of Sb_2Te_3 in the vicinity of its melting point only (Matyas 1971) and in the presence of dopants (Horak *et al* 1975). Kutvitskii *et al* (Kutvitskii *et al* 1970, 1972) have also measured the magnetic susceptibility of Sb_2Te_3 in both solid and molten states. In all these measurements it has been found to be diamagnetic. None of these measurements appear to have been made with single crystals and at different temperatures. We have therefore undertaken to study the principal magnetic susceptibilities $\chi_\perp$ and $\chi_\parallel$, perpendicular to and along the c-axis respectively, of single crystals of Sb_2Te_3, having tetradymite type rhombohedral lattice (Space group : $R\bar{3}m$), over the temperature range 300°K–600°K. The crystals were obtained through the kind courtesy of Dr. P. Bohac of the Swiss Federal Institute of Technology, Zurich. The present communication gives a preliminary account of these measurements.

The experimental procedure consists of the measurement of magnetic anisotropy $\Delta\chi$ $(=\chi_\perp - \chi_\parallel)$ and $\bar{\chi}$ $\left(=\dfrac{2\chi_\perp+\chi_\parallel}{3}\right)$, the mean magnetic susceptibility over the temperature range 300°K–600°K. In view of very feeble temperature variation of susceptibilities at low temperature, $\bar{\chi}$ was measured at 80°K only. All these measurements were carried out in vacuum. It may be pointed out here that though the melting point of Sb_2Te_3 is 894°K, measurements were not made above 600°K because a loss of material due presumably to evaporation was detected above this temperature (600°K).

The specimen is found to be diamagnetic over the entire temperature range. The principal susceptibilities $\chi_\perp$ and $\chi_\parallel$ at room temperature are $-{\cdot}0905\times10^{-6}$ and $-{\cdot}1014\times10^{-6}$ c.g.s. e.m.u. respectively. Both these values increase with the rise of temperature (figure 1a), evidently due to the existence of free charge

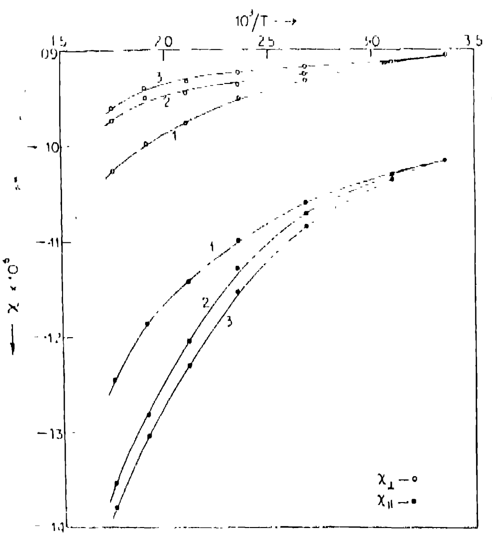

Fig 1a. Variation of observed susceptibility χ with temperature for samples No. (1), (2) and (3)

in it, whose number or distribution or both are sensitive to temperature. The actual values of carrier susceptibilities at different temperatures have been obtained from observed susceptibilities by extrapolating the low temperature values to high temperature and are shown in figure (1b).

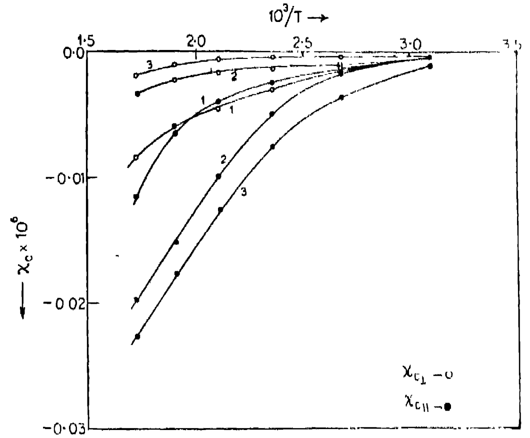

Fig 1b. Variation of carrier susceptibility χ_c with temperature of samples No. (1), (2) and (3).

In an attempt to explain this increase of susceptibility with temperature on the basis of thermal excitation of carriers, it has been observed that results of electrical transport properties indicate (Smirnov 1968)—unlike in case of semi-conductors—no change of carrier numbers with the rise of temperature. A complex valence band model (two valence band model) has therefore been suggested by Rönnlund *et al* 1965) to explain the observed transport properties In this model it is assumed that while the total carrier number in the valence band remains unchanged, there is a redistribution of carriers between two sub bands owing to the temperature dependence of the gap between the sub-band edges, heavier holes in the lower sub-band being excited into the upper sub-band containing lighter and more mobile holes.

The expressions for the mean susceptibilities for the two sub-bands can therefore be written as (Wilson 1958),

$$\bar{\chi}_L(T) = \frac{\mu^2}{k} \cdot \frac{4\pi(2k)^{3/2}}{h^3} \cdot T^{\frac{1}{2}} \left[m_L^{*3/2} F'(\eta) \left(1 - \frac{m_0^2}{3m_L^{*2}} \right) \right] \quad \dots (1)$$

and

$$\bar{\chi}_U(T) = \frac{\mu^2}{k} \cdot \frac{4\pi(2k)^{3/2}}{h^3} \cdot T^{\frac{1}{2}} \left[m_U^{*3/2} F'(\eta - \Delta) \left(1 - \frac{m_0^2}{3m_U^{*2}} \right) \right] \quad \dots (2)$$

where L and U refer to the lower and upper energy sub-bands respectively, F' is the first derivative of Fermi-Dirac integrals (McDougall & Stoner 1938),

$\eta = \xi/kT$, ξ being the Fermi energy, $\Delta = \Delta E/kT$ where ΔE is the gap between the sub-bands and the rest of the symbols have their usual significances.

Hence, the total mean magnetic susceptibility $\bar{\chi}(T)$ is given by

$$\bar{\chi}(T) = \frac{\mu^2}{k} \cdot \frac{4\pi(2k)^{3/2}}{h^3} \cdot T^{\frac{1}{2}} \left[m_L^{*3/2} F'(\eta) \left(1 - \frac{m_0^2}{3m_L^{*2}} \right) \right.$$

$$\left. + m_U^{*3/2} F'(\eta - \Delta) \left(1 - \frac{m_0^2}{3m_U^{*2}} \right) \right] \qquad \ldots (3)$$

We have assumed here, according to Rönnlund *et al* (1965) and Smirnov *et al* (1968), $\Delta = 8{\cdot}7$ (at 300°K) $d(\Delta E)/dT = -1 \times 10^{-4}$ ev/deg, $m_L^*/m_U^* = 1{\cdot}41$. The values of m_L^* and m_U^*, the density of state effective masses of the carriers in the lower and upper sub-bands respectively, have been calculated according to the relation (Putley 1960)

$$m^{*3/2} = m_L^{*3/2} + m_U^{*3/2} \qquad \ldots (4)$$

taking m^* the density of state effective mass to be equal to $\cdot 2963 m_0$ (Horak *et al* 1972). We thereby obtain $m_L^* = \cdot 2169 m_0$ and $m_U^* = \cdot 1538 m_0$. Utilising these values $\chi(T)$ has been calculated at different temperatures and a close fit with our

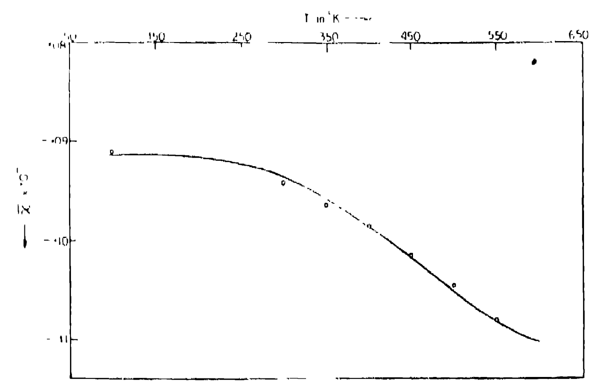

Fig. 2. Variation of mean susceptibility $\bar{\chi}$ with temperature. The solid line represents the theoretical curve and the dots represent the experimental points.

experimentally observed $\bar{\chi} - T$ curve (figure 2) has been obtained for $\eta = 6{\cdot}4$ at 300°K. The Fermi level, therefore, lies within the two sub-bands at room temperatures and it approaches the lower sub-band with the rise of temperature. This is thus quite in conformity with the suggestion of Rönnlund *et al* (1965) that the Fermi level may lie at room temperature, depending on the impurities, anywhere from within the lower sub-band to the lower edge of the upper sub-band.

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NMR study of 2, 4—dihydroxy benzoic acid

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Nuclear Magnetic Resonance studies of 2,4-dihydroxy benzoic acid popularly known as β-resorcyclic acid have been made in the temperature range 77°K to 383°K. An agreement has been observed between the experimental values of proton second moment obtained from the derivative curves of the PMR absorption line for the compound and the calculated value of the proton second moment for rigid lattice, indicating that the lattice is rigid up to the transition temperature. A reduction in the value of proton second moment has been explained as due to the random motion of the hydroxy groups.

The measurement of the variation of NMR absorption lines with temperature in a solid can give valuable information regarding various molecular motions and diffusion process which may be occurring in the compound (Gutowsky & Pake 1950).

The crystal structure of 2,4-dihydroxy benzoic acid was determined by Giacomello *et al* (1956) by a molecular Fourier transform method. The four molecules in a unit cell are arranged in two centrosymmetric dimers related by the center of symmetry of the P_1^- space group. The crystal data : $a = 7{\cdot}05$Å, $b = 9{\cdot}67$Å, $c = 11{\cdot}81$Å, $\alpha = 98°50'$, $\beta = 109°28'$, $\gamma = 91°43'$ and $z = 4$.